

Performances of silicone coated high resistive bakelite RPC

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Abstract

Performances of several single gap (gas gap 2 mm) prototype Resistive Plate Chambers (RPC) made of high resistive ($\rho \sim 10^{10}$ - 10^{12} Ω cm) bakelite, commercially available in India have been studied in recent times. To make the inner electrode surfaces smooth, a thin coating of silicone has been applied. An efficiency $> 90\%$ and time resolution ~ 2 ns (FWHM) have been obtained for both the streamer and the avalanche mode. The induced charge distributions of those silicone coated RPC are studied and the results are presented. A numerical study on the effect of surface roughness of the resistive electrodes on the electric field of the device has been carried out using Garfield-neBEM code. A few results for a simplified model representing surface roughness, measured using a surface profilometer for the bakelite surfaces, have also been presented.

Key words: RPC; Streamer mode; Avalanche mode; Bakelite; Cosmic rays; Silicone; Charge distribution; Garfield-neBEM; Roughness
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1. Introduction

High resistive ($\rho \sim 10^{10}$ - 10^{12} Ω cm) bakelite RPCs [1], prepared with a silicone compound coating on the inner electrode surfaces, were studied in a cosmic ray test bench to characterize its long term stability of operation [2]. Need for the silicone compound coating had been illustrated through the measurement of variation of efficiency with applied high voltage (HV) in our earlier work [2]. Study of variation of time resolution and cross-talk between neighbouring pick-up strips with applied HV were also reported earlier [3,4]. Such high resistive electrode-based RPCs are being explored as active elements of a large scale iron calorimeter for the proposed India-based Neutrino Observatory (INO) [5].

One of the limitations of the streamer mode operation of high resistive bakelite RPCs is that the rate handling capability is relatively worse than that in the avalanche mode. For the same energetic particle falling on the RPC, the charge content contributing to the resulting pulses in the two modes differ by orders of magnitude. This, as well as the physical extent of the streamer and the electron avalanche,

may result in variation of the pulse timing properties. These aspects need to be studied both through experiment and through simulation.

Stability of operation of the RPCs and its dependence on the detector parameters are the other important aspects which need to be studied in detail. It is established that a rough inner electrode surface of an RPC is prone to cause field emission, which is a source of high dark current [6]. In this context, it is relevant to investigate the effect of surface roughness on the detector dynamics. It is conceivable that imperfections on the bakelite surface may be responsible to cause local non-uniformity of the electric field. Depending upon their shape and size, they may often lead to discharge severely degrading the performance of the device.

In this article, some experimental results on operation of our bakelite RPC in the avalanche mode, systematic studies and comparison of charge contents of the resulting pulses in the avalanche mode and the streamer mode operation of the same RPCs are reported. In our endeavor of corroboration of experimental results with simulation, preliminary results of numerical simulation of the effect of roughness of the resistive bakelites on the field configuration are also reported. Using Garfield-neBEM [7,8] code, the field calculation has been done for several models designed on the basis of measurements of the bakelite surface profiles [2].

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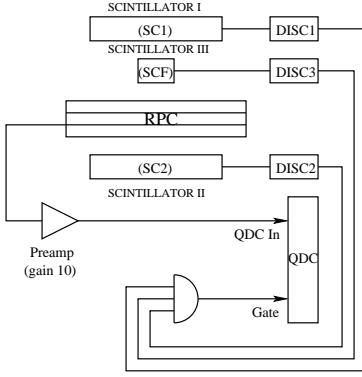


Fig. 1. Schematic representation of the charge spectrum measurement setup. Phillips Scientific 7186 Charge to Digital Converter (QDC) was used.

2. Test setup

All the RPCs were tested in a cosmic ray test bench described in Ref. [2]. The cosmic ray telescope was constructed using three scintillators, two placed above the RPC and one below. Triple coincidence of the signals, obtained from these three scintillators was used to select a cosmic ray event(master trigger). The signals obtained from the pick-up strips were put in coincidence with the master trigger obtained as above. This is referred to as the coincidence trigger. Finally, the efficiency was calculated as the ratio of the coincidence trigger to the master trigger.

Premixed gas of argon, isobutane and tetrafluoroethane(R-134a) in the volume ratio of 55/7.5/37.5 (equivalent to a mass mixing ratio of 34/7/59) was used in the streamer mode, while in the avalanche mode, R-134a/isobutane in 95/5, R-134a/isobutane/SF₆ in 95/4.5/0.5 and 95/2.5/2.5 volume mixing ratio were used. A typical flow rate of 0.4 ml per minute was maintained by the gas delivery system [9], resulting in ~ 3 changes of gas gap volume per day.

Charge content of the pulses were measured using a charge to digital converter, referred to as QDC. The set-up is shown in Fig. 1, which is very similar to that used in Ref. [10]. The master trigger gate of width $1.5 \mu\text{s}$ was also used as gate to the QDC. It was observed that the charge spectrum and the measured mean charge were independent of gate width over a range of 150 ns to $1.5 \mu\text{s}$. The pulse height in the streamer mode was noted to be a few hundred mV, while that in the avalanche mode was found to be < 10 mV. A $10\times$ voltage pre-amplifier was used for the avalanche mode operation of the RPCs.

3. Results

In the avalanche mode, the RPCs were tested using different gas mixtures mentioned as above. The efficiency and time resolution of the RPCs were studied by varying the applied HV. The efficiency plateau was obtained at $> 90\%$ for all the gas mixtures, and it was found to be marginally higher for gas mixtures containing less amount of SF₆. At

the plateau region, the time resolution was found to be ~ 2.5 ns(FWHM) and the average signal arrival time decreased with the increase of HV, which is a common feature of any gas filled detector.

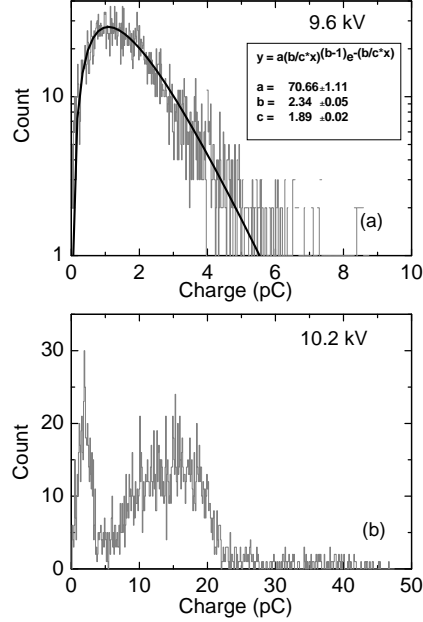


Fig. 2. The charge spectrum of the RPC operated in the avalanche mode using the gas mixture of R-134a/isobutane/SF₆ in 95/4.5/0.5 ratio, at two different high voltages.

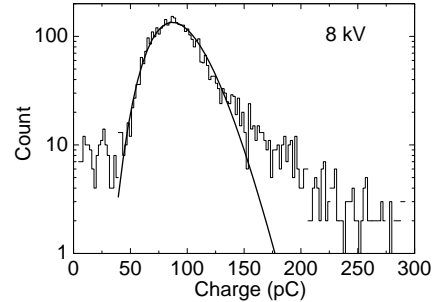


Fig. 3. The charge distribution spectrum in the streamer mode with a gas mixture of Argon/isobutane/R-134a in 55/7.5/37.5 ratio.

In Fig. 2 (a), a typical charge spectrum of the RPC operated in the avalanche mode (HV = 9.6 kV) using the gas mixture of R-134a/isobutane/SF₆ in 95/4.5/0.5 ratio, together with the Polya distribution fitting curve is shown. At higher HV values, a streamer peak appears after the avalanche as shown in Fig. 2 (b). The charge distribution spectrum in the streamer mode with a gas mixture of Ar, isobutane and R-134a in 55/7.5/37.5 ratio is shown in Fig. 3. Corresponding best-fit Polya distribution curve to the streamer charge spectrum is also shown in the same plot. It is clear that the fitted curve underpredicts the pulse charge content at the higher charge tail of the spectrum.

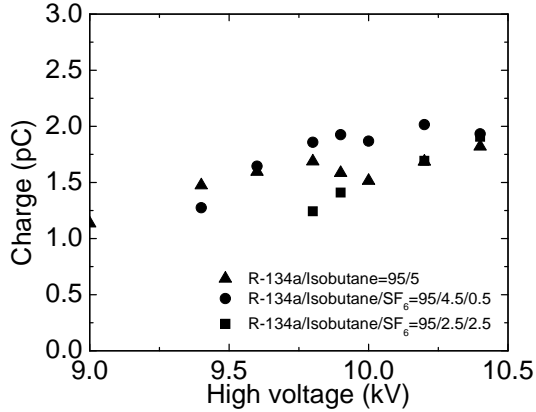


Fig. 4. The induced charge as a function of HV for a silicone coated RPC in the avalanche mode using three different gas mixtures.

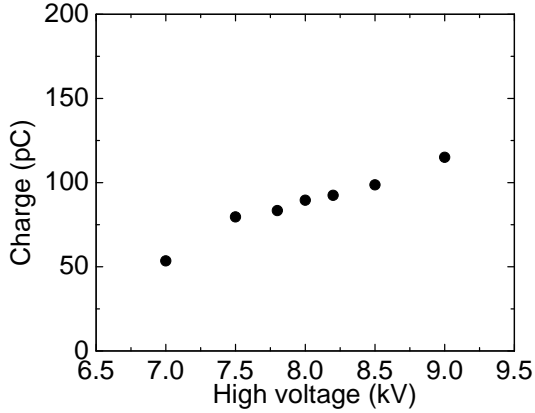


Fig. 5. The induced charge as a function of HV for a silicone coated RPC in the streamer mode with a gas mixture of Argon/isobutane/R-134a in 55/7.5/37.5 ratio.

This possibly indicates the onset of a breakdown mechanism responsible for the excess streamer charge beyond that can be predicted by the clustering model.

The induced charge as a function of the applied HV in the avalanche mode is shown in Fig. 4, whereas that in the streamer mode is shown in Fig. 5. For the RPC, when operated in the avalanche mode with the gas mixtures of R-134a/isobutane in 95/5 and R-134a/isobutane/SF₆ in 95/4.5/0.5 ratio it was observed that at higher voltages a substantial streamer peak appears. But the charge shown in Fig. 4 is the mean charge of the avalanche peak only. It is clear from the figures that the charge saturates at ~ 1 - 2 pC in the avalanche mode for all the gas compositions, while in the streamer mode, the charge is ~ 100 pC.

4. Surface roughness and its effect on the electric field

A preliminary calculation of the electric field to simulate the effect of surface roughness in bakelite RPC has been

done as a proof of concept. The surface profile of the bakelite sheet (Grade P120) has been studied using a DEKTAK 117 profilometer which sampled 2500 times over a small span of 5 cm at three arbitrary locations. Fig. 6 shows the measurement taken at one of these locations where a least square fit has been done in order to define the baseline of the surface. In Fig. 6 the residuals of the data with respect to the baseline are depicted as well to indicate the amplitudes of the roughness. The amplitudes of one such measurement

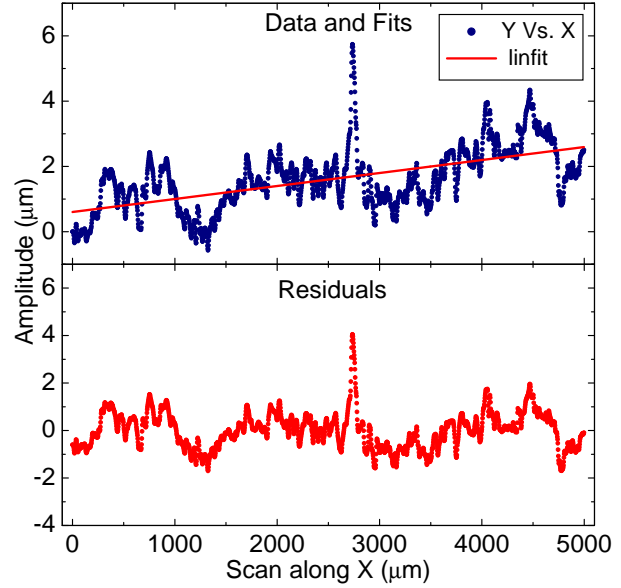


Fig. 6. A typical surface profile of bakelite P120 measured with DEKTAK 117 profilometer. The least square fit to the data and the residuals w.r.t the fit are shown.

is represented in histogram as shown in Fig. 7. It can be found that the maximum amplitudes of the roughness in positive (upward) and negative (downward) directions can be of the order of $4 \mu\text{m}$ and $2 \mu\text{m}$, respectively.

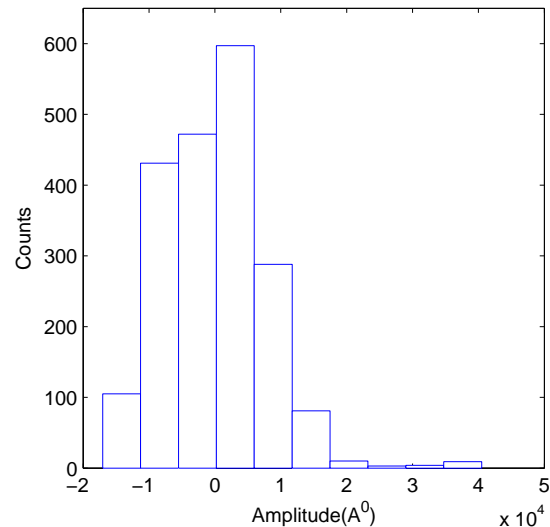


Fig. 7. Histogram of amplitudes with a maximum of $4 \mu\text{m}$.

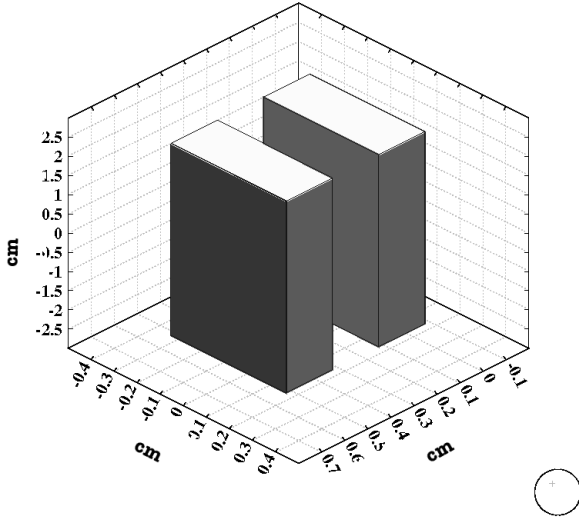


Fig. 8. The model RPC considered in the calculation.

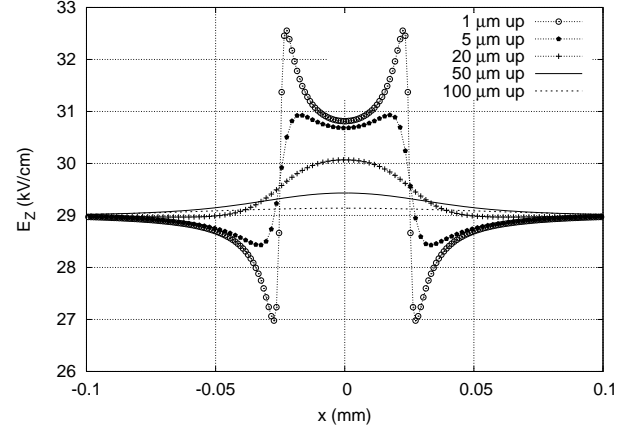


Fig. 9. Variation of electric field with distance away from the positive roughness.

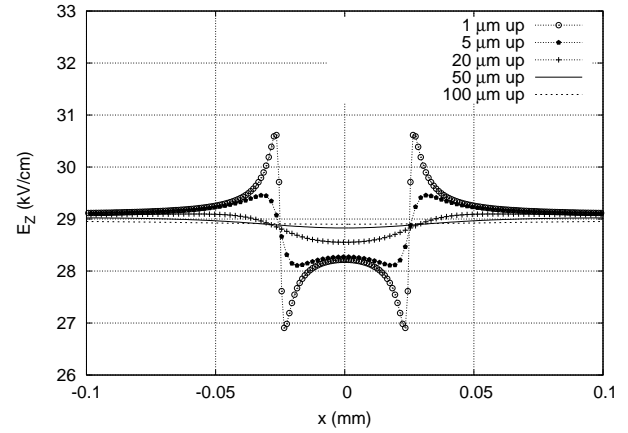


Fig. 10. Variation of electric field with distance near the negative roughness.

5. Conclusions and outlook

Systematic studies on the performances of the silicone coated bakelite RPCs were performed both in the streamer and the avalanche mode. An efficiency $> 90\%$ and time resolution ~ 2 ns (FWHM) were obtained in both the modes of operation. The measured induced charges on the RPC pick-up strips were found to be 1-2 pC in the avalanche mode, and ~ 100 pC in case of the streamer mode of operation. The preliminary calculation proves that the minute structures with straightforward shape on the bakelite surface do affect the field configuration by 5 - 12 % depending on its height or depth in its close proximity. It indicates that the structures with different shapes and sizes may be significant in distorting the nearby field configuration. A detailed study on the roughness structures is therefore required, corroborated by precise measurements to advance the investigation on the effect of roughness on the performance of the RPC.

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